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Magnetron and Travelling Wave Tube

Magnetron. Magnetron forms one of the various high power microwave oscillator and it forms the basis of many a microwave radar transmitter system even nowadays. This microwave generator makes use of magnetic field for producing oscillations at microwave frequencies. Microwave magnetrons now find many applications apart from radar. They are capable of furnishing megawatts of peak power in the centimetre wavelength range and may be operated at wavelengths extending down to millimetre range.

All magnetrons consist of some form of anode and cathode operated in a magnetic field that is normal to the electric field between the cathode and the anode. The magnetic field causes electrons emitted from the cathode to move in curved paths. In case the flux density of the magnetic field is sufficiently great, the electrons do not strike the anode but return to the cathode and the anode current is cut off

Magnetrons form three categories namely

(*a*) Negative resistance magnetrons.

(*b*) Cyclotron frequency magnetrons.

(*c*) Travelling wave magnetrons.

Negative resistance magnetrons make use of a static negative resistance present between two anode electrodes/ plates. Cyclotron frequency magnetrons depend on synchronism between an alter

nating component of electric field and periodic oscillation of electrons in a direction parallel to this electric field. The third type, *i.e.* travelling wave magnetrons depend on interaction of moving electrons with a travelling electro-magnetic field travelling with a constant angular or linear velocity. The frequency of operation for Negative Resistance Magnetrons ranges upto 500 MC. The frequency range for cyclotron frequency magnetrons and travelling wave magnetrons falls beyond 100 MC. Must modern magnetrons come under the category of travelling wave magnetrons.

Constructional features of a cavity magnetron. The cavity magnetron or simply a magnetron is simply a diode usually

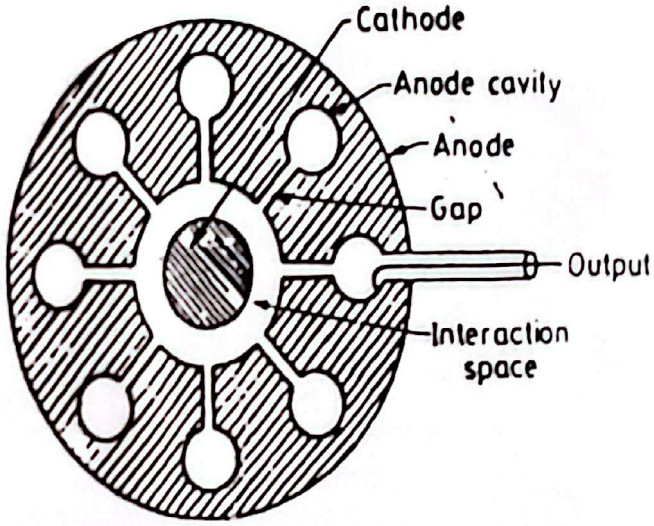
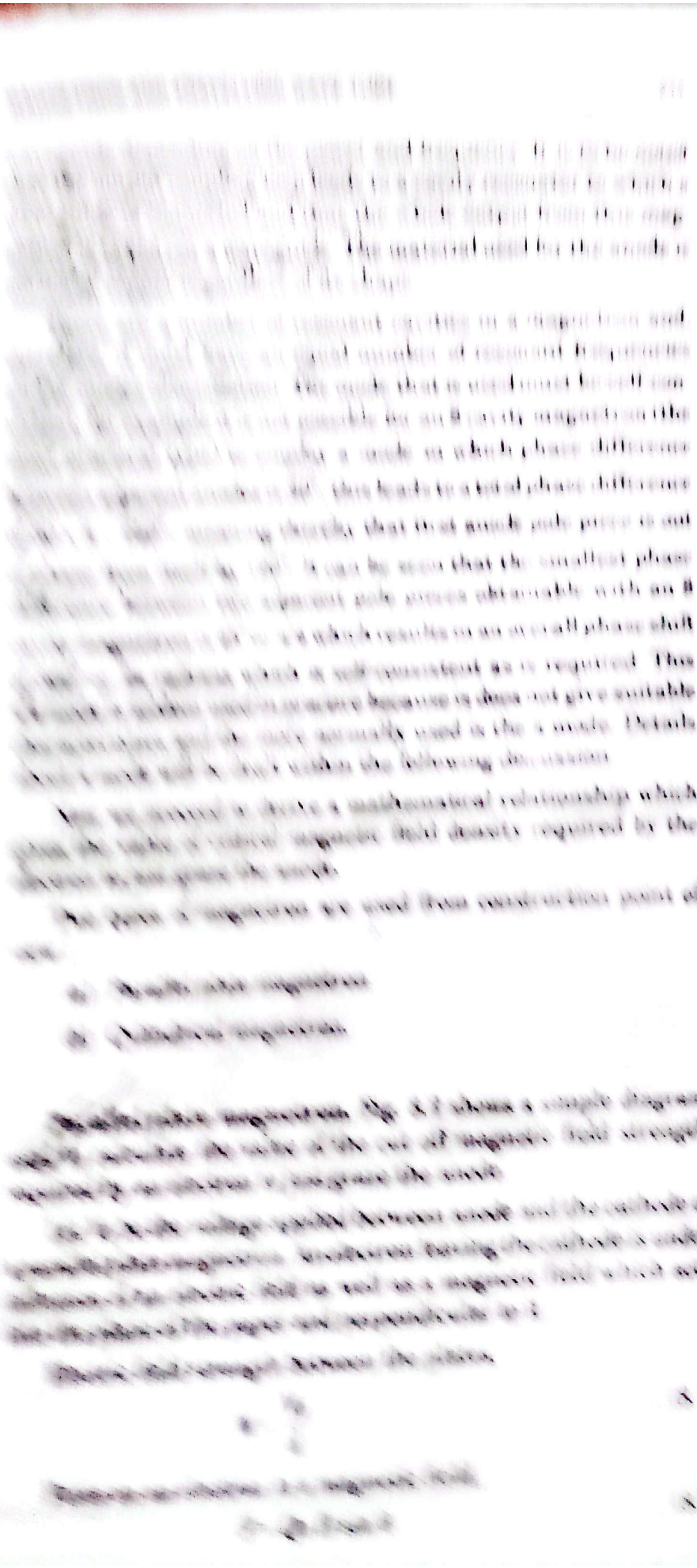


Fig. 8.1. Cross-section of hole and slot magnetron (top view).

of cylindrical construction employing a radial electric field, an axial magnetic field and an anode structure with permanent cavities. Fig. 8.1 shows the cross-section of a HOLE-AND-SLOT magnetron, here the cylindrical cathode is surrounded by the anode with cavities and thus a radial d.c. electric field will exist. The magnetic field due to a horse-shoe type of magnets used in conjunction having the magnetron produces axial magnetic field, *i.e.* has lines of force (magnetic) passing through the cathode and the surrounding interaction space ; therefore, the lines are at right angles to the structure cross-section of Fig. 8.1. The magnetic field is also d.c. and since it is perpendicular to the plane of the radial electric field, the magnetron is referred to as a *Crossed Field* device.

The output of the magnetron is taken from one of the cavities, by means of a co-axial line as is clear from Fig. 8.1 or through a



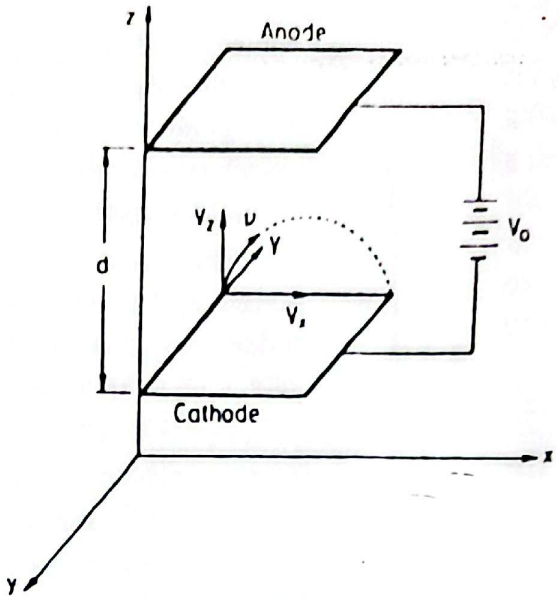


Fig. 8.2.

where θ is the angle made by the magnetic field with the direction of electric field.

If $\theta = 90°$

then $F = QvB$ ...(8.2a)

and the path traced by an electron is a circle. In Eq. (8.2),

Q = charge on electron

v = velocity with which electron moves

B = Magnetic flux density.

Now the force acting on the electron given by Eq. (8.2) is equivalent to a centrifugal force exerted due to motion of electron in a circular path of radius r and is given by Eq. (8.3) as follows :

i.e. we have $$f = \frac{mv^2}{r} = QvB \qquad ...(8.3)$$

so that $$r = \frac{m}{Q}\frac{v}{B} = \frac{m}{e}\frac{v}{B} \qquad ...(8.4)$$

where $Q = e$ = Electronic charge

and r = radius of circle in which the electron moves.

Angular velocity of electron is given as

$$\omega_e = \frac{v}{r} = \frac{eB}{m} \qquad ...(8.5)$$

Vectorially, the force on electron is given as

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$$\bar{f} = e(\bar{v} \times \bar{B} + \bar{E})$$

where v, B, E are velocity vector, magnetic field strength vector and electric field vector respectively, hence magnitude of the force f_z along Z-direction is

$$f_z = m.a_z = -e[E + v_x . B] \qquad ...(8.6)$$

and force (magnitude) along X direction is

$$f_x = m.a_x = +ev_zB \qquad ...(8.7)$$

In above equations a_x and a_z are values of acceleration in X and Z directions respectively.

Eqs. (8.6) and (8.7) may be rewritten as

$$\frac{dv_x}{dt} = \frac{eB}{m} v_z = w_e v_z \qquad ...(8.7a)$$

where $$w_e = \frac{eB}{m} \qquad ...(8.7b)$$

and $$\frac{dv}{dt} = -\frac{eE}{m} - \frac{eB}{m} v_x$$

$$= -w_e v_x + \frac{eV_0}{md} \qquad ...(8.6a)$$

$\left(\because E = -\frac{V_0}{d}\right.$, where V_0 is the voltage applied between two parallel plates)

Differentiation of Eq. (8.6a) yields

$$\frac{d^2v_z}{dt^2} = -w_e \frac{dv_x}{dt}$$

$$= -w_e^2 v_z \qquad ...(8.8)$$

Eq. (8.8) is a differential equation of second degree and its most general solution may be written as

$$v_z = c_1 \sin \omega_e t + c_2 \cos \omega_e t \qquad ...(8.9)$$

Now at $t = 0, v_z = 0 \Rightarrow c_2 = 0$

$$\therefore \quad v_z = c_1 \sin \omega_e t \qquad ...(8.10)$$

Differentiating (8.10) w.r.t. t, we get

$$\frac{dv_z}{dt} = c_1 \omega_e \cos \omega_e t \qquad ...(8.11)$$

Equating Eqs. (8.11) and (8.6a) we obtain

$$c_1 \omega_e \cos \omega_e t = -\omega_e v_x + \frac{eV_0}{m.d}$$

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At $t = 0, v_z = 0$

$$\Rightarrow c_1 \omega_e = \frac{eV_0}{md}$$

or
$$c_1 = \frac{eV_0}{md\omega_e} \quad ...(8.12)$$

So that the solution of (8.9) is obtained as

$$\boxed{v_z = \frac{eV_0}{md\omega_e} \sin \omega_e t} \quad ...(8.13)$$

From Eq. (8.6a), we get

$$v_x = \frac{eV_0}{\omega_e md} - \frac{1}{\omega_e} \cdot \frac{dv_z}{dt}$$

$$= \frac{eV_0}{\omega_e md} [1 - \cos \omega_e t] \quad ...(8.14)$$

Eq. (8.14) is obtained by differentiating Eq. (8.13) and rewriting it in above equation

i.e.
$$\frac{dv_z}{dt} = \frac{eV_0}{md\omega_e} \omega_e \cos \omega_e t$$

$$\Rightarrow \frac{1}{\omega_e} \frac{dv_z}{dt} = \cos \omega_e t \left[\because \frac{eV_0}{md} = \frac{eE}{m} = \omega_e \right]$$

Now Eq. (8.13) can be reproduced here as

$$v_z = \frac{dz}{dt} = \frac{eV_0}{md\omega_e} \sin \omega_e t \quad ...(8.14a)$$

Integrating Eq. (8.13) w.r.t. t gives us

$$z = -\frac{eV_0}{md\omega_e^2} \cos \omega_e t + C \quad ...(8.15)$$

At $t = 0, z = 0$

$$\Rightarrow C = \frac{eV_0}{\omega_e^2 md}$$

$$\therefore \quad z = \frac{eV_0}{md\,\omega_e^2} [1 - \cos \omega_e t] \quad ...(8.16)$$

Similarly from Eq. (8.14), we have

$$v_x = \frac{dx}{dt} = \frac{eV_0}{\omega_e md} (1 - \cos \omega_e t)$$

Differentiating, (8.14) w.r.t. t we get

$$x = \frac{eV_0}{\omega_e md} t - \frac{eV_0}{md\omega_e^2} \sin \omega_e t + C' \quad ...(8.17)$$

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And at $t = 0, x = 0 \Rightarrow C = 0$

so that $$x = \frac{eV_0}{\omega_c md}\left[t - \frac{\sin \omega_c t}{\omega_c}\right] \quad ...(8.18)$$

Eq. (8.16) could be rewritten here

$$z = \frac{eV_0}{m\omega_c^2 d}(1 - \cos \omega_c t) \quad ...(8.16)$$

Now for value of z to be maximum, we have

$$\cos \omega_c t = -1 \Rightarrow \omega_c t = \pi$$

$$\therefore \quad z_{max} = \frac{2eV_0}{m\omega_c^2 d} = \frac{2eV_0/d}{m\left(\frac{eB}{m}\right)^2}$$

or $$z_{max} = 2\frac{m}{e}\frac{V_0}{d}\cdot\frac{1}{B^2} \quad ...(8.19)$$

At $d = z_{max.}$, the electron just grazes off the parallel plate so that we have the expression for cutoff value of magnetic field, B_c as

$$\boxed{B_c = \sqrt{\frac{2mV_0}{ed^2}}} \quad ...(8.20)$$

Eq. (8.20) is an expression for cutoff magnetic field in case of *Parallel plate magnetron*.

Now we proceed on to derive an expression for cut off magnetic field for a cylindrical magnetron.

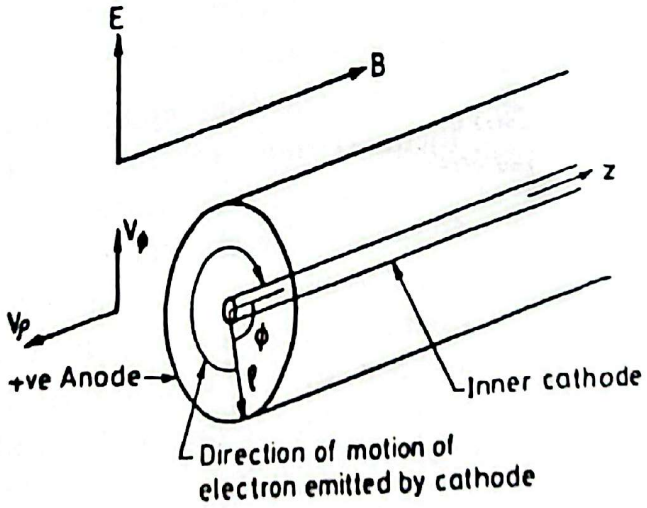

Fig. 8.3. Cylindrical magnetron.

Cylindrical magnetron. A cylindrical magnetron consists of two cylindrical electrodes—the inner one being the negative cathode and the outer one being the anode.